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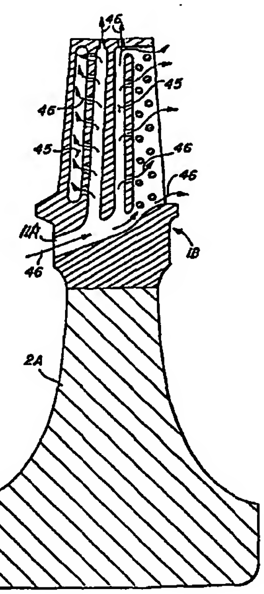
(54) **Dual alloy cooled turbine wheel and method for its manufacture.**

(57) A dual alloy cooled turbine wheel is manufactured by casting a hollow cylinder (1) of first nickel-base alloy material with high creep resistance to produce directionally oriented grain boundaries. A preform (2) of a second nickel-base alloy material with high tensile strength and high low-cycle-fatigue strength is diffusion bonded into the bore (1A) of the hollow cylinder (1) by subjecting the cylinder and preform to hot isostatic pressing. The resulting cylindrical block (10) is cut into thin precisely flat wafers (10A). A plurality of alignable holes (11, 11B) for forming fluid cooling passages are photochemically etched into the individual wafers. The wafers then are laminated together by vacuum diffusion bonding techniques, with the holes (11, 11B) aligned to form fluid cooling passages. The resulting laminated block (10B) is machined to produce the turbine wheel (10C) with turbine blades (13) through which the cooling passages (11, 45) extend.



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DUAL ALLOY COOLED TURBINE WHEEL AND METHOD FOR ITS MANUFACTURE

The invention relates to dual alloy turbine wheels and, more particularly, to dual alloy cooled wheels, and to methods of manufacture thereof.

Various dual alloy turbine wheels are used instead of single alloy turbine wheels in applications in which exceptionally high speed, high temperature operation is needed, since under these circumstances it is necessary to have high creep rupture strength at high temperatures in the blade or outer rim portion of a well designed turbine disk, and it is also necessary under high speed, high temperature conditions to have superior tensile strength and low-cycle-fatigue properties in the hub portion. Superalloy materials which have the former highly desirable characteristics in the blade and outer rim portions of a turbine wheel do not have the high tensile strength and low-cycle-fatigue resistance properties that are required in the hub, and vice-versa. In general, all the desirable qualities for turbine wheel hubs are associated with tough, fine-grained, nickel-base alloys; in contrast to the desired properties of the material of the blade, ring, or rim portions of a turbine disk, in which large-grained, nickel-base alloys with directional structures in the blades are used. The large grained, directional structure alloys possess high creep resistance, but inferior tensile properties.

Where the performance compromises necessitated by use of a single alloy material in a turbine disk are unacceptable, dual alloy turbine wheels have been used for many years, for example, in connection with military engines which utilise AISI Type 4340 alloy steel hubs fusion welded to Timken 16-25-6 warm-worked stainless steel rims, the alloys of which could be fusion-welded to yield joints of adequate strength. More modern, stronger, more complex alloys, however, could not be fusion-welded in typical disk thicknesses without unacceptable cracking. Inertia-welding processes have been used in joining of axial-flow compressor disks into spools and in joining of dissimilar metal shafts to turbine wheels. However, the largest existing inertia welding machines are only capable of welding joints in nickel-based alloys which are a few square inches in cross section, so this process can be used only in the smallest turbine disks.

The bonding of dissimilar metals by hot isostatic pressing (HIP) has been suggested for manufacture of dual alloy turbine wheels, since this process does not have the inherent joint size limitations of the inertia-welding process. Hot isostatic pressing is a process in which the pressure is applied equally in all directions through an inert argon gas in a high temperature pressure vessel or autoclave. Cross U.S. Patent No. 4,096,615, Ewing et al, U.S. Patent No. 4,152,816 and Catlin U.S. Patent No. 3,940,268 are generally indicative of the state of the art for hot isostatic pressing as applied to manufacture of dual alloy turbine wheels. Kirby U.S. Patent No. 3,927,952, assigned to the present assignee, is indicative of the state of the art in

manufacture of cooled turbine disks and discloses photochemically etching recesses in thin single alloy disks to produce corresponding holes which are aligned when the disks are subsequently vacuum diffusion bonded together to create a laminated structure in which fluid cooling passages extend from a central bore of the hub to and through the turbine blades. Cooled turbine discs are necessary in small, high-temperature gas turbine components that are subjected to exceedingly high external gas temperatures, wherein the blade metal temperatures may reach the range of 927 to 982 degrees Celsius (1700 to 1800 degrees Fahrenheit). The cooling passages are necessary to prevent the blades from exceeding this temperature range in order to prevent excessive creep of the blade material.

The above mentioned dual alloy turbine wheels have become attractive because their optimum material properties in both the hub portion area and the ring and blade portion of turbine disks have allowed the minimization or elimination of cooling fluid requirements and have allowed lighter weight turbine disks to be utilised. However, there nevertheless remains a need for an ultra-high performance dual alloy turbine wheel that is capable of operating in conditions that would produce unacceptably high blade temperatures even in the best prior art uncooled dual alloy turbine wheels.

Accordingly, it is an object of this invention to provide an ultra-high performance turbine wheel and a practical method of manufacture thereof which has all of the advantages of prior dual alloy turbine wheels

and further provides suitable fluid cooling passages to the blades of the disk. A turbine wheel having such fluid cooling passages is referred to herein as a cooled turbine wheel.

According to the present invention from one aspect, a method of manufacturing a cooled turbine wheel having a hub portion from which a plurality of blades outwardly extend, comprises the steps of:

(a) providing a central metallic hub portion having high tensile strength and high low-cycle-fatigue strenth;

(b) providing a plurality of thin, annular metallic laminae each having high creep rupture strength;

(c) forming holes through said laminae;

(d) intersecuring said laminae in a stacked relationship in which said holes are relatively oriented to define at least one cooling passage extending through the stacked laminae;

(e) securing the inner edges of said laminae to said central metallic hub portion; and

(f) removing part of said peripheral portions of said laminae to define, in the stacked laminae, said blades.

From another aspect, the present invention comprises a method of manufacturing a cooled turbine wheel having a hub portion from which a plurality of blades outwardly extend, said method comprises the steps of:

(a) providing a plurality of thin, metallic laminae each having a central hub portion with a high tensile strength and high low-cycle-fatigue strength, and a contiguous peripheral portion having high creep rupture strength;

(b) forming holes through said laminae;

(c) intersecuring said laminae in a stacked relationship in which said holes are relatively oriented to define at least one cooling passage extending through the stacked laminae; and

(d) removing part of said peripheral portions of said laminae to define, in the stacked laminae, said blades.

The invention from yet another aspect comprises a cooled, dual alloy turbine wheel comprising: a plurality of thin laminae bonded together to form a laminated dual alloy turbine wheel, each of said laminae including

(a) an outer portion of first superalloy material having high creep rupture strength, said outer portion including a blade ring portion and a plurality of thin blades extending radially outwardly from said blade ring portion;

(b) an inner hub portion of second superalloy material having the properties of high tensile and high low cycle fatigue strength, the outer boundary of said inner hub portion being bonded to the inner boundary of said outer portion; and

(c) a plurality of cooling holes, the cooling holes in said laminae being aligned to form a plurality of fluid cooling passages respectively extending through the respective blades of said dual alloy turbine wheel.

The superalloys referred to are very well known to those skilled in the art and are used to make high-temperature parts in gas turbines. All superalloys include nickel, they all include chromium to provide oxidation strength, they all include aluminium to provide

what is known as gamma prime strengthening, and they all include one or more of the group consisting of tungsten, molybdenum and tantalum. Superalloys are described in the publication "Superalloys 1984" published by the Metallurgical Section of the American Institution of Mechanical Engineers as the proceedings of the "Fifth International Symposium on Super Alloys" at Seven Springs, Mountain Resort, Champion, Pennsylvania, U.S.A.

A preferred superalloy for the material of the outer portion of the turbine wheel from which the blades are formed is that identified by the Trade Mark MAR-M247 of the Martin Marrietta Corporation of Baltimore, Maryland, U.S.A.

A preferred superalloy for use in forming the hub portion of the turbine wheel is a powder-metal low-carbon Astroloy material. Astroloy is a nickel-based superalloy patented by General Electric Co. of USA, who also use the word as a Trade Mark for the alloy. It is also known as Udimet 700 by Special Metals Corporation of New Hartford, N.Y.

Briefly described, and in accordance with one embodiment thereof, the invention provides a high performance, cooled, dual alloy turbine wheel and method of manufacture thereof, wherein a hollow cylinder of first superalloy material having high creep rupture strength up to approximately 982°C (1800°F) is cast against a chill to produce a radial directional grain structure; the hollow cylinder then is filled with second superalloy material having the properties of high tensile and high low-cycle-fatigue strengths, after which deformable plates are bonded to the cylinder

to tightly seal the second superalloy material therein and the assemblage then is subjected to hot isostatic pressing to achieve direct metallurgical diffusion bonding of the second superalloy material to the cast cylinder; the resulting dual alloy cylinder is then sliced into a plurality of thin, precisely flat dual alloy wafers or laminae, which are cut to produce cooling holes, and then are reassembled to produce a laminated cylinder from which the cooled dual alloy turbine wheel can be machined. In the described embodiment of the invention, the first superalloy material of which the cast cylinder is formed consists of MAR-M247 alloy and the second superalloy is in the form of a pre-consolidated preform composed of powder metal low carbon Astroloy material. After the hot isostatic pressing, the resulting dual cylinder alloy cylinder is machined to produce a precise cylinder. Slicing of the resulting dual alloy cylinder into wafers is accomplished by a process that results in precisely flat wafers. Photochemical etching or laser cutting techniques are used to cut cooling holes in locations at which the turbine blades will be formed later. The wafers are coated with elemental boron or a nickel-boron alloy, aligned so that their respective cooling holes form fluid cooling passages, and are subjected to hot axial pressing to vacuum diffusion bond the wafers together to produce the laminated structure. The laminated structure then is appropriately heat treated and inspected, and machined using conventional techniques to form the turbine blades and other features of the turbine wheel. Extremely high creep strength is achieved in the blade material.

Extremely high tensile strength and high low-cycle-fatigue strength are achieved in the hub portion of the turbine wheel. These properties result in an extremely high performance turbine wheel that can withstand very high temperature, high speed operation.

The invention can be carried out into practice in various ways, but specific embodiments thereof will now be described by way of example only, and with reference to the accompanying drawings, in which:

Figure 1 is a perspective view of a cast hollow cylinder of superalloy material having high creep rupture strength, for use in making a turbine wheel embodying the present invention;

Figure 2 is a sectional view of a subsequent step in the manufacture of the turbine wheel illustrating placement of a second alloy preform in the cylinder of Figure 1 and attachment of sealing end caps to prepare the assemblage for hot isostatic pressing;

Figure 3 illustrates a sectional view of the resulting dual alloy cylinder after machining thereof to form a precise cylindrical block;

Figure 4 illustrates slicing of the dual alloy cylinder of Figure 3 into thin, precisely flat dual alloy wafers;

Figure 5 is a plan view illustrating one of the dual alloy wafers of Figure 4 after photochemical etching thereof to produce fluid cooling holes, and illustrating the wrought alloy hub and the cast alloy blade sections thereof;

Figure 6 is a perspective view of the laminated dual alloy cylinder with cooling passages formed therein;

Figure 7 is a perspective view illustrating a completed cooled radial flow turbine wheel formed by machining the laminated cylinder of Figure 6;

Figure 8A is a sectional view of one blade of a cooled axial flow turbine wheel made in accordance with the method of the present invention;

Figure 8B is a sectional view of one blade of another cooled axial flow turbine wheel made in accordance with the method of the invention; and

Figure 9 is a flow diagram useful in explaining the manufacturing process of the present invention.

Referring now to the drawings, reference numeral 1 in Figure 1 designates a cast hollow cylinder. Cylinder 1 is cast of a material having very high creep rupture strength. A suitable material would be a nickel-based superalloy material, such as MAR-M247 material. This material has a relatively high proportion of gamma-prime forming elements. Preferably, the procedure of casting cylinder 1 would be to cast it against a chill (i.e., by providing a chilled copper outer mould wall against which the outer portion of the cast, molten alloy metal presses so that the outer portions of the molten metal freeze rapidly, producing radial, directional solidification. The radial lines shown in Figure 1 on the top of cylinder 1 indicate the resulting radial grain structure. This results in maximum creep rupture strength. Note that this first step (of casting cylinder 1) is designated by reference numeral 35 in the process flow chart of Figure 9.

The next step in the process is to machine a cylindrical hole 1A precisely in cylinder 1 so that a very close

fit can be provided against the surface of a hub preform. The hub preform is designated by reference numeral 2 in Figure 2. As mentioned above, the hub portion of the turbine wheel being manufactured needs to have maximum low-cycle-fatigue and high tensile strength properties. A suitable preform 2 having these properties can be composed of preconsolidated powder metal low carbon Astroloy, a fine grained superalloy material having a lower proportion of gamme-prime forming elements than the MAR-M247 material.

The outer-diameter circumferential face of preform 2 is machined to achieve a precise fit into the machined cylindrical hole 1A into cast cylinder 1. Subsequent to machining the outer circumference of preform 2, it is inserted into the centre of the cast cylinder 1. This step is indicated in block 36 of Figure 9. Normally, the hub preform 2 would be manufactured by hot isostatic pressing techniques to make a cylindrical "log" from which the preforms 2 are machined. After the precise fit has been achieved, two deformable end plates 3 and 4 are peripherally bonded to cast cylinder 1. The bonding can be achieved by the known technique of electron beam welding, which produces electron beam weld spikes 5 to affix and seal the deformable plates 3 and 4 to the cylinder 1. A secondary seal around the preformed hub 1 and deformable plates 3 and 4 is accomplished by brazing the outer circumferences of the deformable plates 3 and 4 to produce activated diffusion bonding that provides the additional seals designated by reference numerals 6 and 7. This step is recited in block 37 in the flow chart of Figure 9. The electron beam welding techniques and peripheral

brazing techniques are well known and can be easily provided by those skilled in the art. The deformable plates 3 and 4 can be composed of Inconel 625 sheets, which are typically 1.016-2.032 mm (.040-.080 inch) thick.

As indicated in block 38 of the flow chart of Figure 9, the next step is to hot isostatically press the assemblage of Figure 2 in order to achieve vacuum diffusion bonding of the hub preform to the cast cylinder 1. The hot isostatic pressing procedure would typically be performed in an autoclave for four (4) hours at 103,421.4kPa (15,000 psi) pressure and 1204°C (2200°F) temperature. Activated diffusion bonding is described in detail in the November 1970 welding research supplement of the Welding Journal of the American Welding Society at pages 505-S to 509-S by George Hoppin III, and T.F. Berry, also incorporated herein by reference.

As indicated by block 39 in the flow chart of Figure 9, the next step in the process for making the dual alloy cooled turbine wheel embodying the present invention is to machine the ends of the assemblages illustrated in Figure 2 and formed by the hot isostatic pressing procedure in order to remove the deformable end plates 3 and 4 and produce a machined cylindrical "log" designated by reference numeral 10 in Figure 3 and having a rectilinear axial section. This rectilinear log is then suitable for the subsequent step which, as indicated in block 40 of Figure 9, is to slice the dual alloy cylinder 10 into a large number of thin, extremely flat dual-alloy wafers or laminae,

generally designated by reference numeral 10A in Figure 4. Typically, the thickness of each of the wafers 10A might be in the range from 0.508 to 1.016 mm (0.020 to .040 inch). Reference numeral 1B in Figure 4 designates the outer alloy portion of a wafer 10A, which has the desired high creep rupture strength needed in the turbine blades, while reference numeral 2A designates the hub portion having the desired fine grained alloy structure with high low-cycle-fatigue and high tensile strength properties.

The degree of flatness required for the wafers 10A is quite high; a flatness of approximately plus or minus one percent of the wafer thickness is desirable. This is in contrast with aircraft engine industry normal standards for sheet thickness, where the tolerance is $\pm 10\%$. Various techniques could be used for slicing the dual alloy log 10 of Figure 3 into the wafers 10A. The presently preferred technique is to use "wire EDM" (electrical discharge machining) devices which are widely used to obtain precise cutting of metals.

As indicated in block 41 of the flow chart of Figure 9, the next step in the manufacturing process of the present invention is to photochemically machine each of the dual alloy disks 10A to form holes 11, 11B which will produce the fluid cooling passages that will be needed in the turbine blades of the cooled turbine wheel ultimately produced by the process of the present invention. Reference numerals 11 in Figure 5 generally designate a particular group of such fluid cooling holes that each forms a portion of one of such

cooling passages which will ultimately extend through one of the subsequently formed turbine blades. Alternatively, other machining techniques could be used, such as laser cutting to produce the fluid cooling holes 11. In Figure 6, holes 11 are the air inlets for the respective blades of the turbine wheel being manufactured. Other cooling fluid holes 11B are shown in the wafer illustrated in Figure 5. Each hole 11, 11B extends through a path, which may be quite complex, in a separate blade of the turbine wheel.

Next, as indicated by block 42 in Figure 9, it is necessary to align the corresponding fluid cooling holes 11, 11B in all of the dual alloy disks 10a so that the fluid cooling passages of the turbine wheel are formed. The disks 10A are all laminated together to produce the reconstructed dual alloy block designated by reference numeral 10B in Figure 6. As mentioned in the above referenced Kirby U.S. Patent 3,927,952, (which is owned by the present assignee and is incorporated herein by reference) the laminated rectangular block 10B can be formed of the thin wafers 10A by coating them with a suitable braze or diffusion bonding alloy, which can be applied in various ways, such as by spraying, dusting, or placing a braze alloy foil between the adjacent wafers. A preferred technique is to deposit elemental boron in carefully controlled amounts by chemical vapour deposition. The coated wafers are then stacked in a predetermined order, with the fluid cooling holes 11, 11B properly aligned, and are subjected to a vacuum diffusion bonding process at a suitable elevated temperature, such as 1204°C (2200°F) under a suitable axial pressing force such as 68.9-689 kPa (10-100 psi).

After appropriately heat treating and inspecting the resulting "log" 10B of Figure 6, the final step in the manufacturing process of the present invention is to utilize conventional machining techniques to produce a cooled, dual alloy turbine wheel, such as the radial flow turbine wheel, designated by reference numera 10C in Figure 7, wherein reference numeral 13 generally designates the blades. Reference numeral 14 generally designates the ends of some of the fluid cooling passages in the blades of the final turbine wheel that are obtained by the above-mentioned photo-chemical machining of holes 11, 11B in the dual alloy disks 10A and proper alignment thereof during the vacuum diffusion bonding procedure by which laminated cylinder 10B is formed.

Although the above example leads to the construction of the cooled radial flow turbine wheel of Figure 7, the same techniques can be applied to the manufacture of axial flow turbine wheels. Figures 8A and 8B show sectional views of blades of two such cooled axial flow turbine wheels. In Figure 8A, reference numeral 2A designates high tensile strength, high low-cycle-fatigue strength material of the hub portion of an axial flow turbine wheel. Reference numeral 1B generally designates the high creep strength blade portion of the turbine wheel. Reference numeral 11 designates the cooling air inlet of the blade, leading to a complex network of air passages 45 formed by properly aligned cooling holes in the various laminate disks. The arrows 46 indicate the general direction of cooling air flow in the passages 45. The cooling air is exhausted from outlets at the tip and the trailing edge of the blade

and through "showerhead" holes in the leading edge of the blade (not shown in Figure 8A). Figure 8B shows another sectional view of the blade of a simpler axial flow turbine wheel, wherein the cooling passages extend from the inlet 11A to outlets only at the tip of the bladeThus, the invention provides a dual alloy turbine wheel that has optimum materials and cooling circuits for a cooled integral turbine wheel. The method also provides a practical method of manufacture of the turbine wheel.

The turbine wheel of the present invention should provide significant advantages for certain small, extremely high speed, high temperature turbine engines.

While the invention has been described with reference to a particular embodiment thereof, those skilled in the art will be able to make various modifications to the described embodiment of the invention without departing from the true spirit and scope thereof. It is intended that elements and steps which are equivalent to those disclosed herein in that they perform substantially the same function in substantially the same way to achieve substantially the same result be encompassed within the invention.

For example, it is not essential that the hub preform 2 be sliced along with the annular cast cylinder 1, since no cooling holes are needed in the hub. Therefore, the annular cast cylinder 1 as shown in Figure 1 could be sliced to produce wafers or disks in which cooling passage holes are cut, as by photochemical etching. These etched disks can be laminated to reconstruct the annular cylinder 1, and the hub preform

2 can then be inserted into the hole (corresponding to 1A in Figure 1) of the reconstructed annular cast cylinder and attached thereto by diffusion bonding.

CLAIMS

1. A method of manufacturing a cooled turbine wheel having a hub portion from which a plurality of blades outwardly extend, said method comprising the steps of:

(a) providing a central metallic hub portion having high tensile strength and high low-cycle-fatigue strength;
(b) providing a plurality of thin, annular metallic laminae each having high creep rupture strength;
(c) forming holes through said laminae;
(d) intersecuring said laminae in a stacked relationship in which said holes are relatively oriented to define at least one cooling passage extending through the stacked laminae;
(e) securing the inner edges of said laminae to said central metallic hub portion; and
(f) removing part of said peripheral portions of said laminae to define, in the stacked laminae, said blades.

2. The method of Claim 1 wherein said hub portion is a solid cylinder composed of preconsolidated powder metal low carbon Astroloy material.

3. The method of Claim 1 or Claim 2 wherein step (b) includes obtaining said annular metallic laminae by casting first superalloy material against a chill to produce a hollow cylinder, and slicing said hollow cylinder to thereby provide said annular metallic laminae.

4. The method of any one of Claims 1 to 3 wherein step (d) includes diffusion bonding said laminae together.

5. The method of any one of Claims 1 to 4 wherein step (e) includes diffusion bonding the inner edges of said laminae to said central metallic hub portion.

6. A method of manufacturing a cooled turbine whee having a hub portion from which a plurality of blades outwardly extend, said method comprising the steps of:

(a) providing a plurality of thin metallic laminae each having a central hub portion with a high tensile strength and high low-cycle-fatigue strength, and a contiguous peripheral portion having high creep rupture strength;

(b) forming holes through said laminae;

(c) intersecuring said laminae in a stacked relationship in which said holes are relatively oriented to define at least one cooling passage extending through the stacked laminae; and

(d) removing part of said peripheral portions of said laminae to define, in the stacked laminae, said blades.

7. The method of Claim 6 wherein step (b) includes forming said holes in said peripheral portions of said laminae.

8. The method of Claim 6 or Claim 7 wherein step (a) includes obtaining said plurality of thin metallic laminae by providing a hollow cylinder of first superalloy material and providing within said hollow cylinder of first superalloy material a close fitting solid cylinder of second superalloy material, bonding said first superalloy material and said second superalloy material together along the entire interface between said hollow cylinder and said solid cylinder to form a solid dual alloy cylinder, and slicing said solid dual alloy cylinder to thereby produce said thin metallic laminae.

9. The method of Claim 8 wherein step (a) also includes the step of casting said first superalloy material against a chill to obtain said hollow cylinder.

10. The method of Claim 8 or Claim 9 wherein said solid cylinder of second superalloy material is composed of preconsolidated powder metal low carbon Astroloy material.

11. The method of any one of Claims 6 to 10 wherein said intersecuring includes subjecting said laminae to hot axial pressing to vacuum diffusion bond said laminae together, said laminae being aligned so that said holes define a plurality of cooling passages, at least one extending through each of said blades.

12. A method of manufacturing a cooled dual alloy turbine wheel having a hub portion and a plurality

of thin blades projecting radially outwardly from said hub portion, said method comprising the steps of:

(a) providing a hollow cylinder of first superalloy material having high creep rupture strength up to a temperature of approximately 982 degrees Celsius (1800 degrees Fahrenheit), said hollow cylinder having an axial hole therein;

(b) filling said hole with second superalloy material having the properties of high tensile strength and high low-cycle-fatigue strength;

(c) bonding a first imperforate deformable plate to said cylinder to cover said hole and tightly seal said second superalloy material in said hole;

(d) subjecting said sealed cylinder and second superalloy material therein to hot isostatic pressing at a predetermined temperature and a predetermined pressure to effect direct metallurgical diffusion bonding of said second superalloy material to the cast first superalloy material of said cylinder to form a unitary dual alloy cylinder;

(e) transversely slicing said cylinder into a plurality of relatively thin, precisely flat wafers;

(f) forming a plurality of holes in each of said wafers at predetermined locations thereof;

(g) aligning and stacking said wafers and subjecting them to axial pressing at a predetermined temperature to vacuum diffusion bond said wafers into a laminated dual alloy cylinder with the holes forming fluid cooling passages extending in blade locations in said laminated dual alloy cylinder whereat said thin blades are to be subsequently formed; and

(h) machining said laminated dual alloy cylinder to produce said thin blades, said fluid cooling passages extending through various ones of said blades, respectively, to form said cooled dual alloy turbine wheel with blades having high creep rupture strength up to approximately 982 degrees Celsius (1800 degrees Fahrenheit) and with said hub having an ultimate tensile strength of at least 1,034,214 kPa (150,000 psi).

13. The method of Claim 12 wherein step (a) includes casting said first superalloy material against a chill to produce large radially oriented grain boundaries that result in high creep rupture strength in the blades of said turbine wheel.

14. The method of Claim 13 wherein said first superalloy material is a cast nickel base superalloy containing a relatively high proportion of gamma-prime forming elements and said second superalloy material is a wrought nickel base superalloy containing a lower proportion of gamma-prime forming elements than said first superalloy material.

15. The method of any one of Claim 12 to 14, wherein step (c) includes bonding a second imperforate deformable plate to an opposite end of said hole to tightly seal said second superalloy material in said hole.

16. The method of Claim 15 including bonding said first and second imperforate deformable plates to said cylinder by electron beam welding to effect a vacuum seal between said cylinder and said first and second imperforate deformable plates, respectively.

17. The method of Claim 15 including bonding said first and second imperforate deformable plates to said cylinder by brazing to effect a vacuum seal between said cylinder and said first and second imperforate deformable plates, respectively.

18. The method of any one of Claims 12 to 17 wherein said second superalloy material is in the form of a pre-consolidated powder preform and step (b) includes positioning said preform in said hole to produce an essentially zero tolerance fit between said preform and the wall of said hole.

19. The method of any one of Claims 12 to 18 wherein said first superalloy material is a cast nickel-based superalloy material.

20. The method of any one of Claims 12 to 19, wherein said second superalloy material is pre-consolidated powder metal low carbon Astroloy material.

21. The method of any one of Claims 12 to 20 wherein said hot isostatic pressing is conducted in an autoclave at a temperature of approximately 1204 degrees Celsius (2200 degrees Fahrenheit) at a pressure of at least approximately 103,421.4 kPa (15,000 psi).

22. The method of any one of Claims 12 to 21 wherein steps (e), (f) and (g) are performed before step (b).

23. A method of manufacturing a cooled dual alloy turbine wheel having a hub portion and a plurality of thin blades projecting radially outwardly from said hub portion, said method comprising the steps of:

(a) producing a hollow cylinder of first superalloy material having high creep rupture strength, said hollow cylinder having an axial hole therein;

(b) filling said hole with second superalloy material having the properties of high tensile strength and high low-cycle-fatigue strength and permanently bonding said second superalloy material to said first superalloy material;

(c) slicing said cylinder into a plurality of relatively thin, precisely flat wafers;

(d) forming a plurality of holes in each of said wafers at predetermined locations thereof;

(e) aligning and stacking said wafers and bonding said wafers into a laminated dual alloy cylinder with the holes forming fluid cooling passages extending through blade locations in said laminated dual alloy cylinder whereat said thin blades are to be subsequently formed; and

(f) machining said laminated dual alloy cylinder to produce said thin blades, said fluid cooling passages extending through various ones of said blades, respectively, to form said cooled dual alloy turbine wheel with blades having high creep rupture strength and with said hub having high low-cycle-fatigue and tensile strengths.

24. The method of any one of the preceding Claims, in which the step of forming said holes comprises photo-chemically etching said holes in said laminae or wafers.

25. A cooled, dual alloy turbine wheel comprising:

a plurality of thin laminae bonded together to form a laminated dual alloy turbine wheel, each of said laminae including

(a) an outer portion of first superalloy material having high creep rupture strength, said outer portion including a blade ring portion and a plurality of thin blades extending radially outwardly from said blade ring portion;

(b) an inner hub portion of second superalloy material having the properties of high tensile and high low-cycle-fatigue strength, the outer boundary of said inner hub portion being bonded to the inner boundary of said outer portion; and

(c) a plurality of cooling holes, the cooling holes in said laminae being aligned to form a plurality of fluid cooling passages respectively extending through the respective blades of said dual alloy turbine wheel.

26. The cooled dual alloy turbine wheel of Claim 25, in which said outer portion is of a first superalloy having a high creep rupture strength up to a temperature of approximately 982 degrees Celsius (1800 degrees Fahrenheit), and has an axial hole therein; and in which the inner hub portion fills the said axial hole and is of a second superalloy material having a high tensile strength of at least approximately 1,034,214 kPa.

27. The cooled, dual alloy turbine wheel of Claim 25 or Claim 26, wherein said first superalloy material of said peripheral blade portion has been cast against a chill to produce large, radially oriented grain boundaries that result in high creep rupture strength in said thin blades.

28. The cooled dual alloy turbine wheel of any one of Claims 25 to 27, wherein said first superalloy material is cast, nickel base superalloy material containing a relatively high proportion of gamma-prime forming elements and said second superalloy material is wrought nickel base superalloy material of a lower proportion of gamma-prime forming elements than said first superalloy material.

29. A cooled turbine wheel having a hub portion and a plurality of radially outwardly extending blades, said turbine wheel comprising:

(a) a central metallic portion having high tensile strength and high low-cycle-fatigue strength; and

(b) a plurality of stacked, intersecured thin metallic laminae, said laminae

(i) each circumscribing said central metallic portion and being bonded thereto,

(ii) each having high creep rupture strength,

(iii) defining said blades, and

(iv) having holes formed therethrough which collectively define cooling passages extending through said blades.

30. The cooled turbine wheel of Claim 29 wherein said central metallic portion includes a solid cylinder of preconsolidated powder metal low carbon Astroloy material.

31. The cooled turbine wheel of Claim 29 or Claim 30 wherein said laminae are diffusion bonded together.

32. The cooled turbine wheel of any one of Claims 29 to 31 wherein said laminae are composed of first superalloy material that has been cast against a chill to produce large radially oriented grain boundaries that result in high creep rupture strength in said blades.

33. The cooled turbine wheel of any one of Claims 29 to 32 wherein said central metallic portion has tensile strength of at least approximately 1,034,214 kPa (150,000 pounds per square inch), and said laminae have high creep rupture strength up to a temperature of approximately 982 degrees Celsius (1800 degrees Fahrenheit).

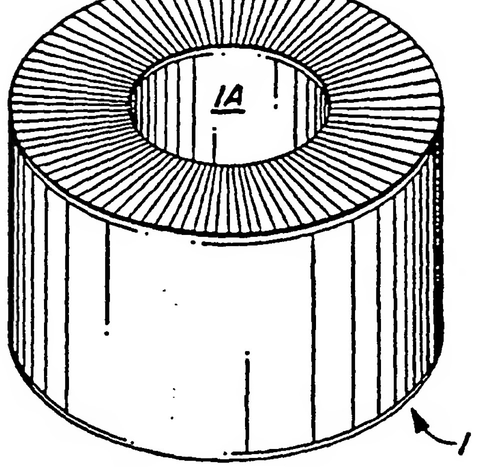


FIG-1

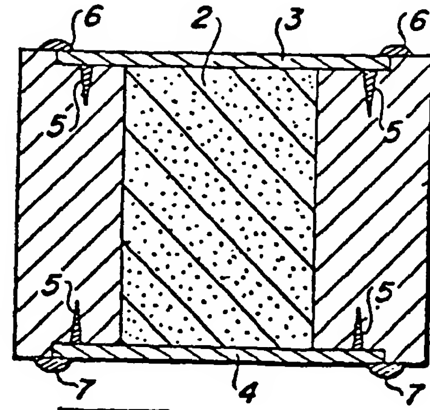


FIG-2

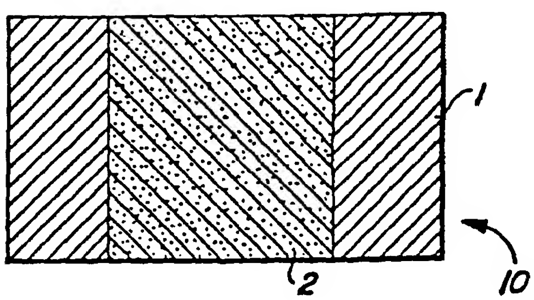


FIG-3

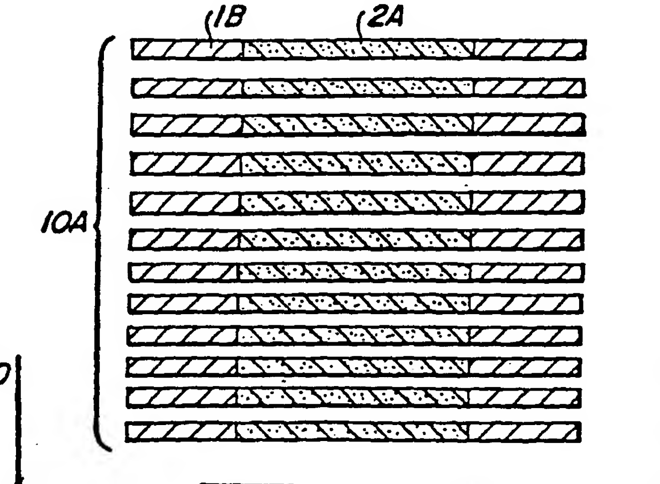


FIG-4

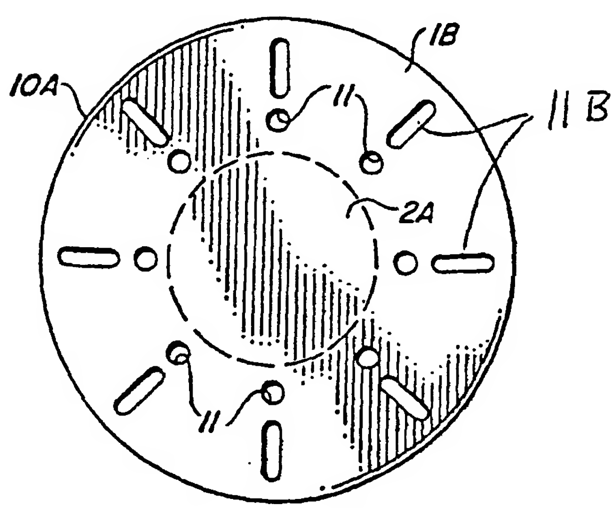


FIG-5

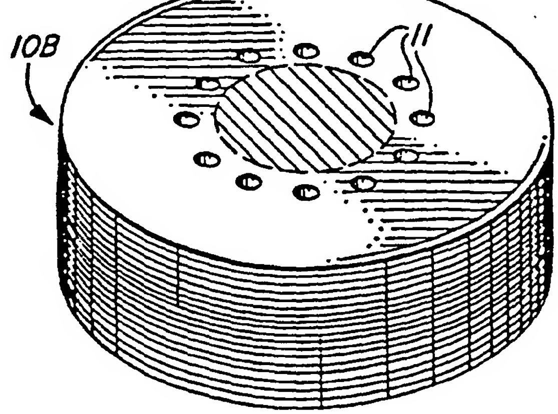
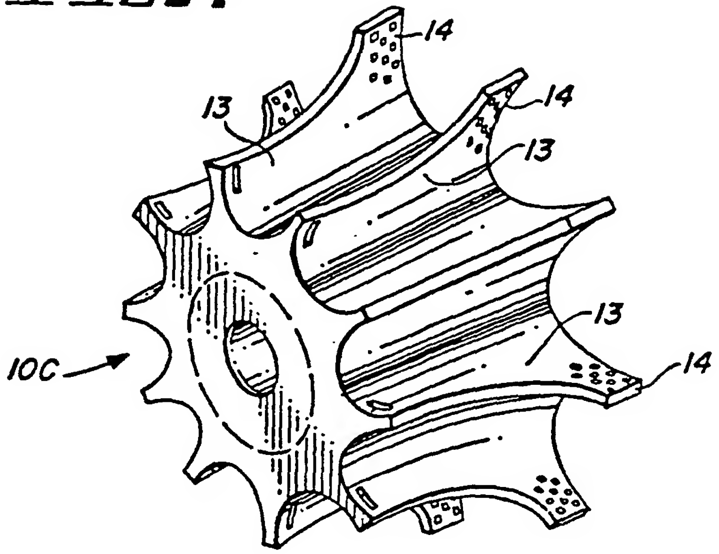


FIG-6

0164272

FIG. 7



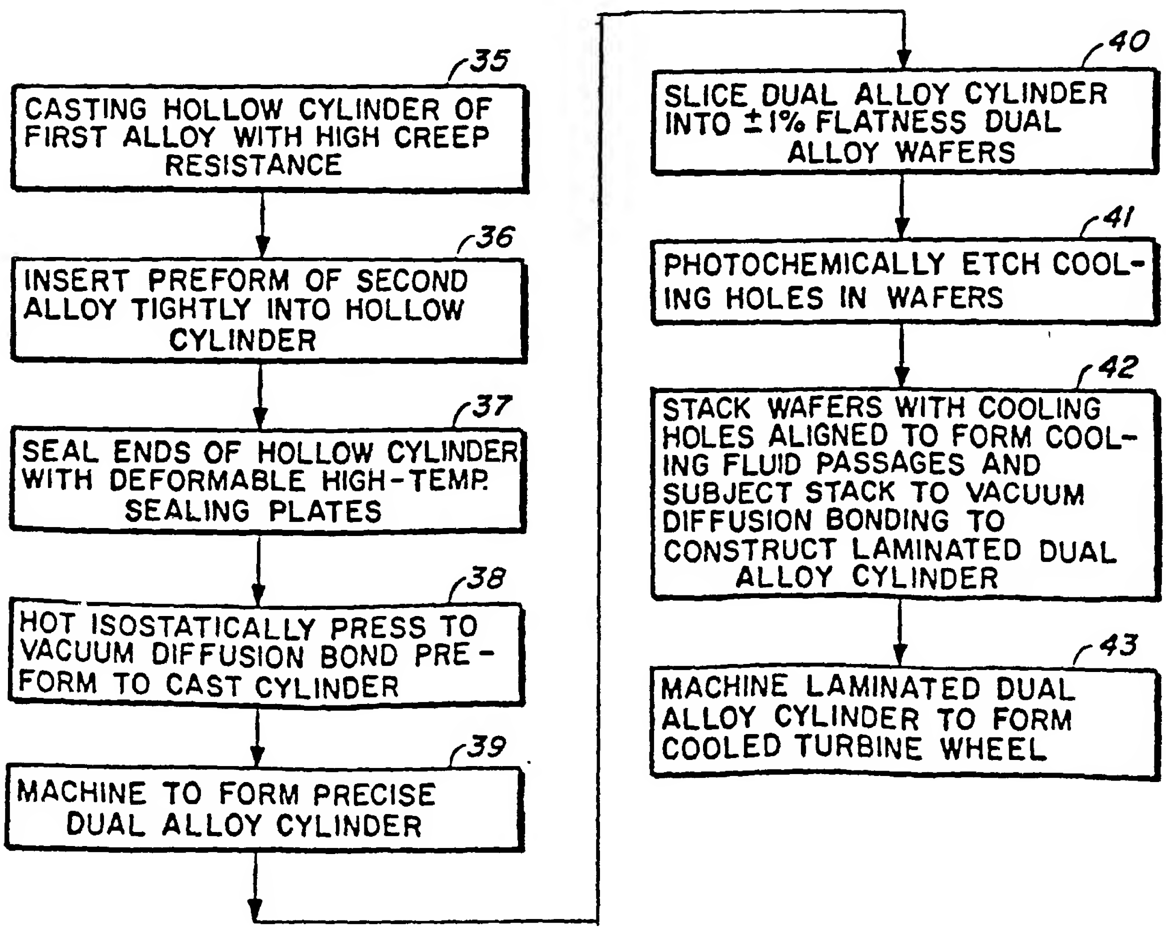


FIG. 9

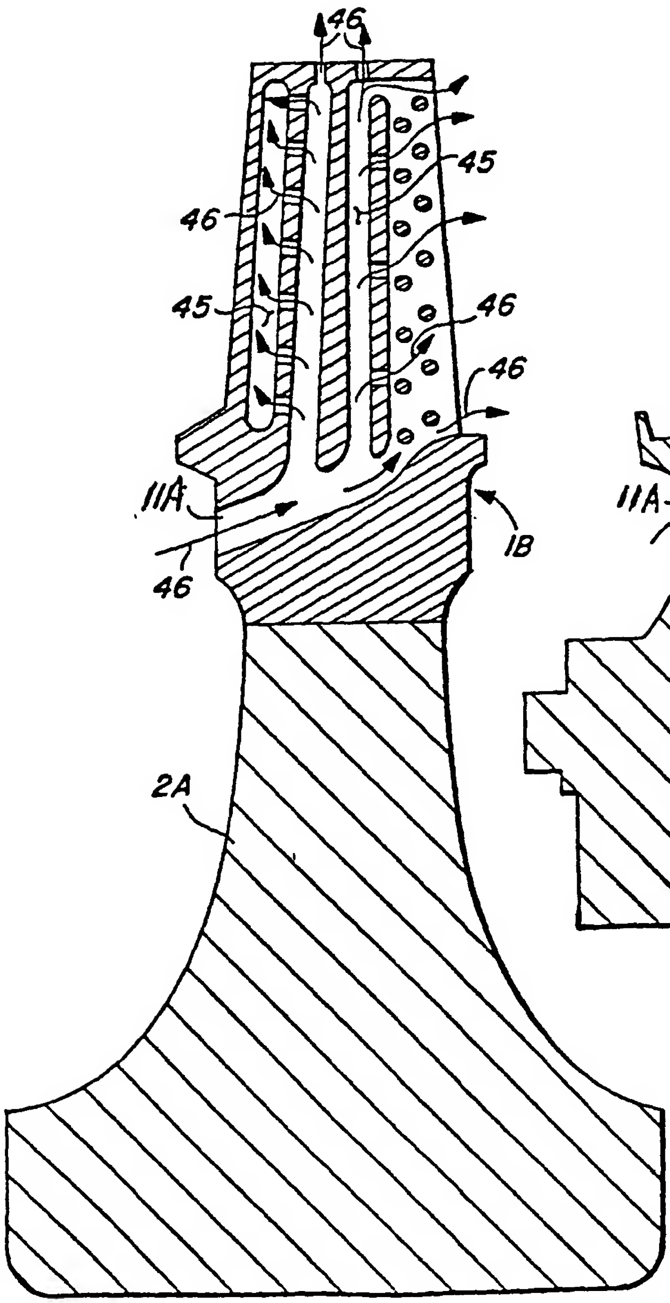


FIG. 8A

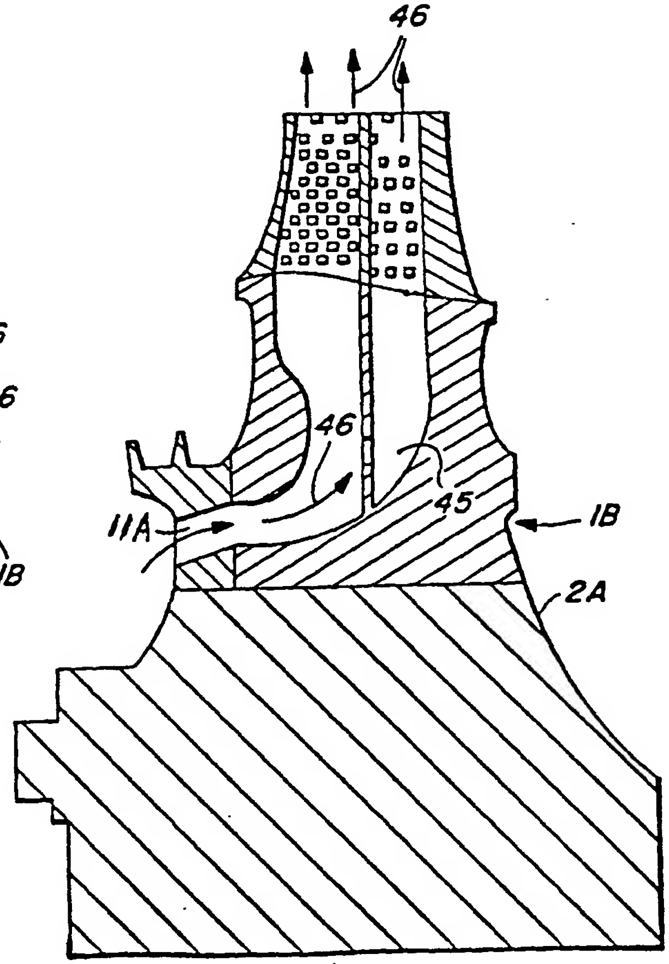


FIG. 8B